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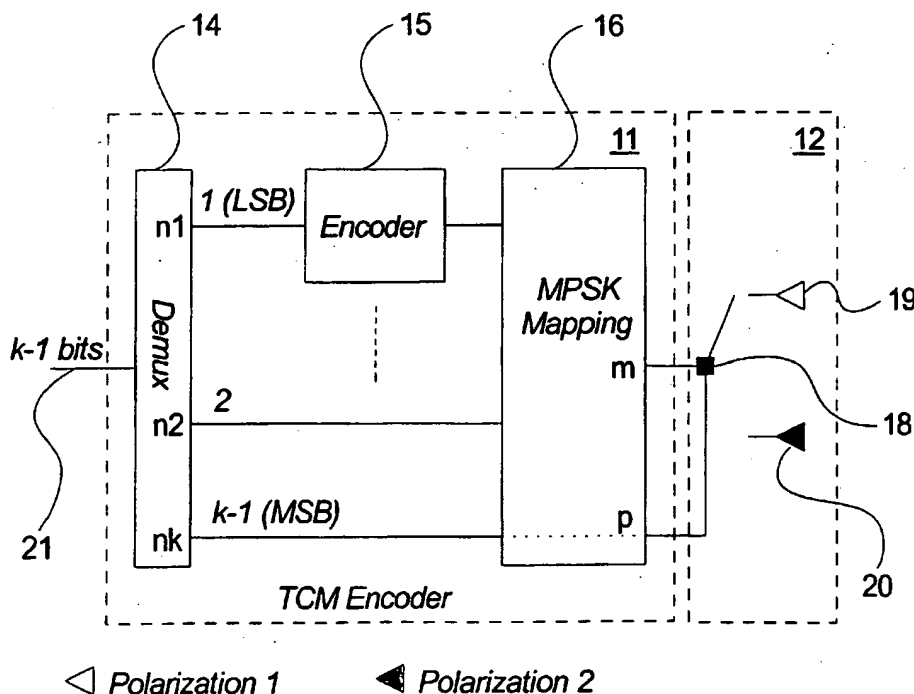
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(54) Title: **ANTENNA POLARIZATION CODULATION**



(57) Abstract: Method of and system for transmitting digital data signals whereby a modulation of the digital signals is performed and whereby a coding by means of antenna polarization of the digital data signals is involved. Hereby an integration of transmit antenna polarization with modulation is achieved, providing improved performance and robustness.

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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

## ANTENNA POLARIZATION CODULATION

**Field of the invention**

5 The invention relates to a method for transmission of digital data signals according to the preamble of claim 1, a method for receiving digital data signals according to the preamble of claim 8, a system for transmission of digital data signals according to the preamble of claim 9, a transmitter for transmission of digital data signals according to the preamble of claim 14, a receiver for receiving transmitted signals according to  
10 the preamble of claim 21, a transceiver for transmitting and receiving digital data signals according to the preamble of claim 25 and uses according to claim 29 and 30.

**Background of the invention**

15 As greater demands are placed on available spectrum resources, the need for bandwidth and power efficient modulation becomes increasingly important, especially in wireless and mobile communication systems. MPSK modulation is employed in many wireless and mobile systems. Under ideal conditions, coherent MPSK is more power efficient than non-coherent, or differentially coherent  
20 modulation techniques. However, the wireless and mobile communication channels are not ideal. Fading is common and delay and delay variation may be significant. The overall performance benefit is a function of the improved bandwidth and power efficiency, as well as, the channel-error rate and delay and their influence on higher-level protocols, such as TCP/IP.

25

MPSK TCM offers bandwidth and power advantages over ordinary MPSK. It is especially interesting to users with small terminals, where bandwidth and power efficiency are at a premium. In addition to increasing the capacity in terms of the number of users that can be supported, the bandwidth efficiency of TCM may also  
30 facilitate the use of newer more bandwidth intensive multimedia applications. For example, over mobile satellite and wireless radio links, where the available

bandwidth and power are limited. Indeed, it is currently employed in commercial satellite modems, such as INTELSAT.

Prior related art is described in for example

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Q1875 Pragmatic Trellis Decoder Technical Data Sheet, QUALCOMM Inc., San Diego, 1992.

10 A. Viterbi, J. K. Wolf, E. Zehavi, R. Padovani, "A Pragmatic Approach to Trellis-Coded Modulation", IEEE Communications Magazine, July 1989.

H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990. H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990.

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J. Farserotu, On Wide Area Networking via ATM over Ka-band SATCOM with CDMA, PhD. Thesis, page 64 and page 150, Delft University of Technology, Delft, 1 December 1998.

20 J. Farserotu, "A Performance Analysis of MPSK TCM", Wireless Personal Communications An International Journal, Kluwer publishers, vol. 8, no. 3, December 1998.

Further reference shall be made to International Patent Application no.  
25 PCT/DK01/00050 ("System for communication" by Prasad, Jyoti et al) which is hereby incorporated by reference.

### Summary of the invention

30 One of the objectives of the present invention is to provide an improved method of and a system for performing communication, especially wireless and mobile communication.

It is a further objective to provide such a method and a system with improved bandwidth and with a power efficient modulation.

- 5 Further, it is an objective to provide such a method and a system having improved performance and robustness.

These and other objectives are achieved by the invention as explained in the following.

10

As specified in claim 1, the invention relates to a method of transmitting digital data signals whereby a modulation of the digital data signals is performed and whereby a coding by means of antenna polarization of the digital data signals is involved.

- 15 Hereby an integration of transmit antenna polarization with modulation is achieved, providing improved performance and robustness. In particular, an enhanced effective distance in the signal space between channel symbols is achieved by the method, whereby performance is enhanced.

- 20 The method according to the invention, which also is referred to as Antenna Polarization Codulation APC is a new technique that integrates antenna polarization and modulation into a new and inventive form of codulation.

- 25 Preferably, as specified in claim 2, said coding may involve a switching of antenna polarization between two different polarization values, whereby a polarization coding may be facilitated in an advantageous and relatively uncomplicated manner.

In a further preferred embodiment, as specified in claim 3, a switching of antenna polarization between at least three different polarization values may be performed.

30

Hereby an embodiment providing further enhanced performance may be achieved.

Advantageously, as specified in claim 4, said modulation may be of the M-nary Phase Shift Keying (MPSK)-type, in particular of the M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type, whereby a modulation type generally available may be used. Further, the MPSK TCM, and in particular the "Pragmatic"-  
5 type is advantageous since it is relatively simple to implement and can be implemented using commercially readily available equipment.

By integrating antenna polarization with MPSK or MPSK TCM a new, more efficient and robust modulation technique is formed.

10

However, the method according to the invention as specified in claim 1 may utilize a wide range of modulations and is not limited to MPSK, MPSK TCM or Pragmatic MPSK TCM.

15 In a further preferred embodiment, as specified in claim 5, said switching of antenna polarization may be determined by means of at least one bit of a digital package, e.g. a byte or a symbol, which bit may be coded or left uncoded by the modulation performed, whereby an advantageous embodiment is achieved.

20 In a further preferred embodiment, as specified in claim 6, said switching of antenna polarization may be determined by means of a most significant bit MSB, which may be coded or left uncoded by the modulation performed, whereby an advantageous embodiment is achieved.

25 In a preferred simple embodiment said switching may be performed on the basis of a most significant bit MSB, which is left uncoded by the modulation performed, whereby a preferred simple embodiment is achieved. Other forms may be preferred dependent on whether the emphasis is on ease of implementation or performance. A simple implementation will be described in the detailed description below. However,  
30 more sophisticated implementations are possible and may be advantageous where efficiency is at a premium.

Alternatively, as specified in claim 7, said switching of antenna polarization may be determined by means of a least significant bit LSB, which may be coded or left unencoded by the modulation performed, whereby another advantageous embodiment is achieved.

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As specified above, the switching may be performed on the basis of MSB, LSB or any other bit(s), e.g. also on the basis of combinations of bits. The choice will depend on ease of implementation vs. performance. Further, it is important to note that the selection of polarization need not be based on the unencoded bit. Coded bit or bits  
10 may also be employed to select the polarization in a comprehensive implementation of antenna polarization modulation (e.g. multidimensional space-time-polarization coding scheme for use with MIMO (multiple input multiple output) antennas), but this may require special equipment, e.g. special codecs.

15 As specified in claim 8, the invention also relates to a method of receiving digital data signals transmitted according to a method according to one or more of claims 1 – 7 whereby a demodulation of the received digital data is performed involving a decoding of the antenna polarization coding and a demodulation in accordance with the modulation involved.

20

The invention also relates to a system as specified in claim 9 for transmission of digital data signals comprising means for facilitating a modulation of the digital data signals to be transmitted and means for facilitating a switching of antenna polarization between at least two different polarizations.

25

Hereby a system is provided whereby an integration of transmit antenna polarization with modulation is achieved, and whereby performance and robustness is improved. In particular, an enhanced effective distance in the signal space between channel symbols is achieved by the system, whereby performance is enhanced.

30

The system according to the invention, which also is referred to as Antenna Polarization Codulation APC is a new technique that integrates antenna polarization and modulation into a new and inventive form of codulation.

- 5 In a preferred embodiment, as specified in claim 10, said system may comprise means for receiving transmitted signals, said means for receiving transmitted signals comprising means for performing a decodulation of said signals involving means for performing a decoding in dependence on antenna polarization of the received digital data and means for performing a demodulation in accordance with the modulation  
10 involved.

Hereby an advantageous embodiment is provided.

- Preferably, as specified in claim 11, said means for performing a modulation and/or  
15 said means for performing a demodulation may operate according to a M-nary Phase Shift Keying (MPSK)-modulation type, in particular to a M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type.

- Hereby the system according to the invention may be constructed using a modulation  
20 type generally available. Further, the MPSK TCM, and in particular the "Pragmatic"-type is advantageous since it is relatively simple to implement and can be implemented using commercially readily available equipment.

- By integrating antenna polarization with MPSK or MPSK TCM a new, more  
25 efficient and robust codulation technique is formed.

- However, the system according to the invention as specified in claim 9 may utilize a wide range of modulations and is not limited to MPSK, MPSK TCM or Pragmatic MPSK TCM.

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In a preferred embodiment, as specified in claim 12, said means for transmitting signals and/or said means for receiving transmitted signals may comprise a number



of antennas preferably corresponding to the number of polarizations utilized, whereby the system may be designed and constructed in an cost-effective and relatively uncomplicated manner.

- 5 Alternatively, as specified in claim 13, said means for transmitting signals and/or said means for receiving transmitted signals may comprise an antenna facilitating transmission and/or reception of signals involving multiple polarizations, preferably corresponding to the number of polarizations utilized.
- 10 The invention further relates to a transmitter as specified in claim 14 for transmission of digital data signals comprising means for facilitating a modulation of the digital data signals to be transmitted and means for facilitating a switching of antenna polarization between at least two different polarizations.
- 15 In a preferred embodiment, as specified in claim 15, said means for performing a modulation may be operating according to a M-nary Phase Shift Keying (MPSK)-modulation type, in particular to a M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type.
- 20 Hereby the transmitter according to the invention may be constructed using a modulation type generally available. Further, the MPSK TCM, and in particular the "Pragmatic"-type is advantageous since it is relatively simple to implement and can be implemented using commercially readily available equipment.
- 25 By integrating antenna polarization with MPSK or MPSK TCM a new, more efficient and robust codulation technique is formed.

However, the transmitter according to the invention as specified in claim 14 may utilize a wide range of modulations and is not limited to MPSK, MPSK TCM or

30 Pragmatic MPSK TCM.

In a further preferred embodiment, as specified in claim 16, said switching of antenna polarization may be determined by means of at least one bit of a digital package, e.g. a byte or symbol, which bit may be coded or left uncoded by the modulation performed, whereby an advantageous embodiment is achieved.

5

In a further preferred embodiment, as specified in claim 17, said switching of antenna polarization may be determined by means of a most significant bit MSB, which may be coded or may be left uncoded by the modulation performed and which serves as or establishes a control input for a switching device, whereby an advantageous embodiment is achieved.

10

Alternatively, as specified in claim 18, said switching of antenna polarization may be determined by means of a least significant bit LSB, which may be coded or left uncoded by the modulation performed and which serves as or establishes a control input for a switching device, whereby another advantageous embodiment is achieved.

15

As specified above, the switching may be performed on the basis of MSB, LSB or any other bit(s), e.g. also on the basis of combinations of bits. The choice will depend on ease of implementation vs. performance. Further, it is important to note that the selection of polarization need not be based on the uncoded bit. Coded bit or bits may also be employed to select the polarization in a comprehensive implementation of antenna polarization modulation (e.g. multidimensional space-time-polarization coding scheme for use with MIMO (multiple input multiple output) antennas), but this may require special equipment, e.g. special codecs.

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In a further preferred embodiment, as specified in claim 19, the transmitter may comprise a number of antennas preferably corresponding to the number of polarizations utilized, whereby the transmitter may be designed and constructed in an cost-effective and relatively uncomplicated manner.

30

Alternatively, as specified in claim 20, the transmitter may comprise an antenna facilitating transmission of signals involving multiple polarizations, preferably corresponding to the number of polarizations utilized, whereby a further advantageous embodiment is achieved.

5

As specified in claim 21, the invention also relates to a receiver for receiving transmitted signals, said receiver comprising means for performing a decodulation of said signals involving means for performing a decoding in dependence on antenna polarization of the received digital data and means for performing a demodulation in accordance with the modulation involved.

10

Preferably, as stated in claim 22, means for performing a demodulation may be operating according to a M-nary Phase Shift Keying (MPSK)-modulation type, in particular a M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type.

15

Hereby the receiver according to the invention may be constructed using a modulation type generally available. Further, the MPSK TCM, and in particular the "Pragmatic"-type is advantageous since it is relatively simple to implement and can be implemented using commercially readily available equipment.

20

By integrating antenna polarization with MPSK or MPSK TCM a new, more efficient and robust codulation technique is formed

25

However, the receiver according to the invention as specified in claim 21 may utilize a wide range of demodulations and is not limited to MPSK, MPSK TCM or Pragmatic MPSK TCM.

30

In a preferred embodiment, as specified in claim 23, said means for receiving transmitted signals may comprise a number of antennas corresponding to the number of polarizations utilized, whereby the receiver may be designed and constructed in an cost-effective and relatively uncomplicated manner.

Alternatively, as specified in claim 24, said means for receiving transmitted signals may comprise an antenna facilitating reception of signals involving multiple polarizations, preferably corresponding to the number of polarizations utilized, whereby a further advantageous embodiment is achieved.

As specified in claim 25, the invention also relates to a transceiver for transmitting and receiving digital data signals said transceiver comprising means for facilitating a modulation of the digital data signals to be transmitted, means for facilitating a switching of antenna polarization between at least two different polarizations and means for receiving transmitted signals, wherein said means for receiving transmitted signals comprises means for performing a decodulation of said signals involving means for performing a decoding in dependence on antenna polarization of the received digital data and means for performing a demodulation in accordance with the modulation involved.

In a preferred embodiment, as specified in claim 26, said means for performing a modulation and/or said means for performing a demodulation may be operating according to a M-nary Phase Shift Keying (MPSK)-modulation type, in particular a M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type.

Hereby the transceiver according to the invention may be constructed using a modulation type generally available. Further, the MPSK TCM, and in particular the "Pragmatic"-type is advantageous since it is relatively simple to implement and can be implemented using commercially readily available equipment.

By integrating antenna polarization with MPSK or MPSK TCM a new, more efficient and robust codulation technique is formed.

However, the transceiver according to the invention as specified in claim 25 may utilize a wide range of modulations and is not limited to MPSK, MPSK TCM or Pragmatic MPSK TCM.

In a further preferred embodiment, as specified in claim 27, said means for transmitting signals and/or said means for receiving transmitted signals may comprise a number of antennas corresponding to the number of polarizations  
5 utilized, whereby the transceiver may be designed and constructed in an cost-effective and relatively uncomplicated manner.

Alternatively, as specified in claim 28, said means for transmitting signals and/or said means for receiving transmitted signals may comprise an antenna facilitating  
10 transmission and/or reception of signals involving multiple polarizations, preferably corresponding to the number of polarizations utilized, whereby a further advantageous embodiment is achieved.

Further, the invention relates to a use as specified in claim 29 of a method according  
15 to one or more of claims 1 - 8, a system according to one or more of claims 9 - 13, a transmitter according to one or more of claims 14 - 20, a receiver according to one or more of claims 21 - 24 and/or a transceiver according to one or more of claims 25 - 28 for wireless communication.

20 Finally, the invention relates to a use as specified in claim 30 of a method according to one or more of claims 1 - 8, a system according to one or more of claims 9 - 13, a transmitter according to one or more of claims 14 - 20, a receiver according to one or more of claims 21 - 24 and/or a transceiver according to one or more of claims 25 - 28 for wireless and mobile communication.

25

By the invention an integration of transmit antenna polarization with modulation is achieved in order to increase the Euclidean distance between transmitted symbols and, therefore, performance and robustness is improved. The new technique according to the invention, referred to as Antenna Polarization Codulation (APC),  
30 may be applied to a wide range of modulation schemes employed in wireless and mobile communication systems, such as, multiple phase shift keying (MPSK). An

example of the application of APC to MPSK Trellis Coded Modulation (TCM) is presented below along with an analysis of the potential performance improvement.

By integrating antenna polarization with MPSK or MPSK TCM a new, more  
5 efficient and robust codulation technique is formed.

However, as explained above, a wide range of modulation schemes may be utilized in connection with the invention.

#### 10 The figures

The invention will be described in further detail below with reference to the drawings of which

- 15 fig. 1 shows a schematic illustration of a system according to an embodiment of the invention,
- fig. 2 shows an embodiment of a transmitter for operating according to the Antenna Polarization Codulation technique (APC) according to the invention and utilizing M-nary Phase Shift Keying (MPSK) Trellis
- 20 Code Modulation (TCM), e.g. 8-PSK example as illustrated,
- fig. 3 illustrates an Antenna Polarization Codulation (APC) M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM) constellation with two polarization zones (8-PSK example), and
- fig. 4 illustrates the performance improvements in AWGN and Rayleigh
- 25 Fading achieved by Antenna Polarization Codulation technique (APC) according to a simple embodiment of the invention.

#### Detailed description

- 30 The method and the system according to the invention will initially be described in general terms with reference to figure 1 which generally shows a schematic illustration of a system according to an embodiment of the invention.

The system comprises a transmitter arrangement 1 and a receiver arrangement 2 for transmitting a signal 3. The transmitter arrangement 1 comprises a modulation arrangement 4, which may utilize any suitable type of modulation, e.g. M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM). Further, the transmitter arrangement 1 comprises an antenna polarization device 5.

Correspondingly, the receiver arrangement 2 comprises an antenna depolarization device 7 corresponding to the antenna polarization device 5 and a demodulator arrangement 8 corresponding to the modulation arrangement 4.

A signal 3, e.g. a digital data signal, is led to the transmitter arrangement 1, and a signal processing involving a modulation and an antenna polarization, i.e. a codulation (coded modulation) is performed before the codulated signal 6 is transmitted to the receiver arrangement 2. In the receiver arrangement 2 a decodulation is performed involving a depolarization and a demodulation leading to an output signal 9.

Obviously, the transmitter arrangement 1 and the receiver arrangement 2 may both be designed as transceiver arrangements, whereby two-way communication may readily be established.

By the generally described method and system, whereby antenna polarization coding and modulation is integrated, a number of advantages are achieved which will be described in further detail below.

The basic Antenna Polarization Codulation technique, which also will be referred to as APC in the following, will be further explained with reference to fig. 2.

In order to help explain APC according to the invention, an example is presented in which APC is applied to M-nary Phase Shift Keying (MPSK) Trellis Code

Modulation (TCM), also referred to in the following as MPSK TCM. Without loss of generality, a form of MPSK TCM known as "Pragmatic" MPSK TCM is considered. The "Pragmatic" MPSK TCM technique is generally available and is described for example in

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Q1875 Pragmatic Trellis Decoder Technical Data Sheet, QUALCOMM Inc., San Diego, 1992, in

10 A. Viterbi, J. K. Wolf, E. Zehavi, R. Padovani, "A Pragmatic Approach to Trellis-Coded Modulation", IEEE Communications Magazine, July 1989, and in

H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990. H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990.

15

The "Pragmatic" MPSK TCM is considered because it is relatively simple to implement and can be constructed using a commercial-off-the-shelf codec (coder-decoder). The application of APC to Pragmatic MPSK TCM is correspondingly simple.

20

An illustration is provided by figure 2, showing a transmitter arrangement, generally designated 10, according to an embodiment of the invention. The transmitter arrangement 10 comprises a TCM encoder 11 and an antenna polarization arrangement 12. The TCM encoder 11 comprises as illustrated a demultiplexer 14, an  
25 encoder 15 and a MPSK mapping device 16. The antenna polarization arrangement 12 comprises a switching device 18 and two antenna devices 19 and 20, each being designed for a specific polarization of the received signal, e.g. a right hand polarization and a left hand polarization.

30 In the example illustrated in fig. 2 a separate polarization per antenna has been employed. However, multiple polarizations per antenna may be utilized as well, for example in certain advanced implementations. For example, multiple feeds per



antenna capable of supporting more than one polarization per antenna are possible and embodiments comprising such arrangements are comprised within the scope of the application.

- 5 An input signal 21 in the form of an input bit stream is split into  $k-1$  separate parallel streams by the demultiplexer 14. One bit stream is passed through the encoder 15, e.g. a standard convolutional encoder, while the remaining streams are passed unencoded through the TCM encoder 11. Assuming a standard rate ( $r$ )  $r = 1/2$  convolutional encoder,  $k-1$  bits are input to the TCM encoder and  $k$  bits are output, such that, the effective code rate is  $r = (k-1)/k$ .
- 10

For example, consider the case of 8PSK TCM implemented using a standard  $r = 1/2$  convolutional encoder. Two information bits are input to the TCM encoder 11; one is encoded by the  $r = 1/2$  convolutional encoder 15 and the other is passed through unencoded to MPSK mapping device 16. This becomes the most significant bit (MSB). Thus, there are three channel bits out of the TCM encoder. The effective code rate of the TCM encoder is  $2/3$  and the three output bits are used to select one of the 8-PSK symbols (i.e.,  $M = 2^k$ ). At the receiver, a hard decision is effectively made on the unencoded MSB. Performance is dependent on the distance in signal space between channel symbols. This is where APC according to the invention in particular offers advantages.

15

20

APC according to the invention increases the effective distance in signal space between channel symbols through the use of different antenna polarizations. In figure 2, two antennas 19, 20 and corresponding polarizations are shown with switching dependent on the MSB (e.g., right hand polarized when the MSB = 1 and left hand polarized when the MSB = 0) and performed by the switching device 18.

25

In the more general case, multiple polarizations, e.g. involving 2, 3 4 or more different polarizations may be employed to further enhance performance (e.g., in the case of higher order MPSK TCM). Furthermore, although implementation may be

30

more complex, APC with polarization switching based on other than the MSB may be advantageous from a performance perspective.

Further, multiple polarizations per antenna, e.g. involving 2, 3 4 or more different polarizations pr. antenna may be utilized as well, for example in certain advanced implementations. For example, multiple feeds per antenna capable of supporting more than one polarization per antenna are possible and embodiments comprising such arrangements are comprised within the scope of the invention.

10 Figure 3 depicts the APC constellation with two polarization zones for the case of 8PSK TCM. From this figure, it can be seen that if the separation between polarizations is large enough, half the potential symbol transitions are eliminated. The actual performance benefit depends on the symbol error rate, the number of bits in error per symbol and, ultimately, on the distance in signal space between channel  
15 symbols.

In the following, an analysis shall be performed in order to examine the performance benefit of APC. Continuing with the 8-PSK TCM example, the unencoded MSB may be either a 1 or a 0 and the channel symbols out of the Pragmatic TCM encoder may  
20 be grouped into two zones shown in figure 3. For example, if the output of the  $r = 1/2$ , constraint length 7, convolutional encoder is 11, then the channel symbol would be either 011 or 111, where the digit to the far right is the MSB, which selects the antenna polarization.

25 At the receiver, a hard decision is effectively made on the MSB based on the detected phase change relative to the carrier phase reference. In the case of 8-PSK, this becomes one out of two information bits output from the MPSK TCM decoder. Soft decision decoding of the relative phase change is considered to proceed without knowledge of the MSB. The second information bit is the output of an Viterbi  
30 decoder (i.e., for decoding the underlying convolutional code).

In effect, there are two possible channel symbols associated with each state transition in the trellis, which may be viewed as parallel paths through the trellis: one symbol if the unencoded bit is a 0 and another if the unencoded bit is a 1 (cf. e.g. H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990, and H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990.).

As a result, one might expect that the pairwise error bound per channel use for 8-PSK may be viewed as having two components,  $D_{n0}(\alpha_{n0})$  and  $D_{n1}(\alpha_{n1})$ . Similarly, 16-PSK TCM would have 4 components and 32-PSK TCM would have 8 components.

The contributions to the pairwise error bound are averaged over the possibility that the MSB was either a 1 or a 0, with equal probability. In the case of Pragmatic MPSK TCM, the Viterbi decoder is not considered to have knowledge of the MSB. Consequently, a relative phase change of the same magnitude and sign results in the same output from the Viterbi decoder, regardless of the MSB. An error leads to a 180 degree phase error. Normally, the probability that a 180 degree phase (i.e., between antipodal signal pairs) is assumed to be very small, relative to transitions between neighboring signals in the constellation, but this is not always true (e.g., at low values of  $E_b/N_0$ ).

In order to determine the performance improvement possible with APC according to the invention, the baseline performance of MPSK TCM must first be evaluated. This requires computation of the average pairwise error bound. In the case of the Pragmatic MPSK TCM example, we begin by evaluating the average error weight profile

$$\overline{F(B, E_n, D(\alpha))} = \sum_{\alpha} a_{\alpha} D(\alpha / MSB = 0) \cdot p(MSB = 0) + a_{\alpha} D(\alpha / MSB = 1) p(MSB = 1).$$

(Equation 1)

$E_n$  is the error frame at time  $n$ ,  $a_{\alpha}$  is the number of channel signals in the set that have a squared Euclidean error weight  $\alpha$ . The number of branches emerging from a

node in the trellis is  $L = 2^{l-k}$ , where  $r = \frac{k-1}{k}$  (cf. H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990. H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990.).

5

For a rate  $2/3$  code, this means that  $L = 1/4$ . However, since a separate decision on the MSB is made and the remaining bits are separately decoded (i.e., via a Viterbi decoder), then  $L = 1/2$  because the rate of the underlying convolutional code is  $r = 1/2$ .

Now, using the modified generating function approach to performance modeling of Pragmatic MPSK TCM (cf. the above cited reference "Practical Applications of TCM"), with the above changes, gives rise to the error weight profiles of Table 1, which have been normalized according to the number of branches  $L$ .

10

Table 1: Normalized error weight profiles for Pragmatic 8-PSK TCM

15

| Signals      | Error pattern | $\overline{F(B, E_s, D(\alpha_s))}L$ |
|--------------|---------------|--------------------------------------|
| (000 or 100) | 000           | $2D(\alpha_0)$                       |
| (001 or 101) | 001           | $D(\alpha_1) + D(\alpha_5)$          |
| (010 or 110) | 010           | $D(\alpha_2) + D(\alpha_6)$          |
| (011 or 111) | 011           | $D(\alpha_3) + D(\alpha_7)$          |

The probability of bit error may now be evaluated by combining equation (1), with the weight profiles in Table 1, based on the modified generating function approach (cf. H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990. H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990.)

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$$P_b \leq \frac{1}{b} \frac{\partial T(P(X \rightarrow \hat{X}), I, L)}{\partial I} \bigg|_{I=1} = \frac{1}{b} \sum_{i=1}^{\infty} \sum_{d=d_f}^{\infty} ia(d, i) \prod_{n=1}^N \overline{F(B, E_n, D(\alpha_n))} L.$$

(Equation 2)

The methodology for computing the basic weight profiles is detailed in the above cited reference ("Practical Applications of TCM"). However, there are differences between the weight profiles herein and those computed based on above cited reference ("Practical Applications of TCM"). The differences arise due to the handling of the unencoded bit(s) associated with Pragmatic TCM and averaging of the weight profiles over the unencoded MSB. This is important with respect to APC, since it directly relates to the antenna polarization and the process of reception and decoding. An example follows. Consider the case of the path at the minimum Hamming distance from the correct path. The sequence of codewords along the path of minimum Hamming distance is

110 → 001 → 110 → 110 → 000 → 010 → 110,

A single bit error results in a departure from the all 0s path. The minimum Hamming distance along this path is 10 and seven codewords are transmitted  $N = 7$  before reconvergence with the all 0s path. The contribution to the probability of bit error may be computed from equation 2 as

$$P_b \leq \frac{1}{2} \left[ \frac{1}{2} \cdot 1 \cdot (D(\alpha_3) + D(\alpha_7))^4 \cdot (D(\alpha_1) + D(\alpha_5))^1 \cdot (2D(\alpha_0))^1 \cdot (D(\alpha_2) + D(\alpha_6))^1 \right].$$

The results that follow were calculated using the contributions to the  $P_b$  from paths at Hamming distance 10 and 12 in the unmodified generating function. The contributions to the  $P_b$  from paths at Hamming distance 10 are provided in Table 2. Note that the dependence on  $n$  in  $D_n(\alpha_n)$  has been dropped. Slow fading with interleaving is assumed such that the symbols are independent. Performance

modeling is described in e.g. the prior art references cited above and more details concerning performance modeling are described in these and in particular in

5. A. Viterbi, J. K. Wolf, E. Zehavi, R. Padovani, "A Pragmatic Approach to Trellis-Coded Modulation", IEEE Communications Magazine, July 1989, in

H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990. H. Dehesh, R. Kerr and A. Viterbi, "Practical Applications of TCM", QUALCOMM Inc., IEEE MILCOM, August 1990, and in

10

J. Farserotu, "A Performance Analysis of MPSK TCM", Wireless Personal Communications An International Journal, Kluwer publishers, vol. 8, no. 3, December 1998.

- 15 Table 2: Contribution to  $P_b$  from terms at Hamming distance 10

|  |
|--|
| $1 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^4 \cdot (D(\alpha_1) + D(\alpha_5))^1 \cdot (2 \cdot D(\alpha_0))^1 \cdot (D(\alpha_2) + D(\alpha_6))^1 \right]$ |
| $3 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^2 \cdot (D(\alpha_1) + D(\alpha_5))^5 \cdot (2 \cdot D(\alpha_0))^1 \cdot (D(\alpha_2) + D(\alpha_6))^1 \right]$ |
| $4 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^2 \cdot (D(\alpha_1) + D(\alpha_5))^2 \cdot (2 \cdot D(\alpha_0))^4 \cdot (D(\alpha_2) + D(\alpha_6))^4 \right]$ |
| $2 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^3 \cdot (D(\alpha_1) + D(\alpha_5))^1 \cdot (2 \cdot D(\alpha_0))^1 \cdot (D(\alpha_2) + D(\alpha_6))^3 \right]$ |
| $3 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^3 \cdot (D(\alpha_1) + D(\alpha_5))^4 \cdot (2 \cdot D(\alpha_0))^0 \cdot (D(\alpha_2) + D(\alpha_6))^4 \right]$ |
| $5 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^2 \cdot (D(\alpha_1) + D(\alpha_5))^3 \cdot (2 \cdot D(\alpha_0))^5 \cdot (D(\alpha_2) + D(\alpha_6))^3 \right]$ |
| $6 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^2 \cdot (D(\alpha_1) + D(\alpha_5))^8 \cdot (2 \cdot D(\alpha_0))^0 \cdot (D(\alpha_2) + D(\alpha_6))^6 \right]$ |
| $2 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^3 \cdot (D(\alpha_1) + D(\alpha_5))^3 \cdot (2 \cdot D(\alpha_0))^3 \cdot (D(\alpha_2) + D(\alpha_6))^1 \right]$ |
| $3 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^2 \cdot (D(\alpha_1) + D(\alpha_5))^3 \cdot (2 \cdot D(\alpha_0))^2 \cdot (D(\alpha_2) + D(\alpha_6))^3 \right]$ |
| $3 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^3 \cdot (D(\alpha_1) + D(\alpha_5))^2 \cdot (2 \cdot D(\alpha_0))^4 \cdot (D(\alpha_2) + D(\alpha_6))^2 \right]$ |
| $4 \cdot \left[ (D(\alpha_3) + D(\alpha_7))^2 \cdot (D(\alpha_1) + D(\alpha_5))^2 \cdot (2 \cdot D(\alpha_0))^6 \cdot (D(\alpha_2) + D(\alpha_6))^4 \right]$ |

Knowledge of only a few paths is required when  $E_b/N_0$  is large, as the higher order terms (i.e., greater Euclidean distance) drop off quickly. However,  $E_b/N_0$  seen by the receiver in a fading channel is time varying and not always large. Margin is required and systems designed with excess margin are inefficient. Further, systems employing concatenated codes, diversity and advanced processing tend to operate at relatively low values of  $E_b/N_0$ , where the benefits of the proposed technique are largest.

Figure 4 illustrates the performance improvements in AWGN (Additive White Gaussian Noise) and Rayleigh Fading achieved by Antenna Polarization Codulation technique (APC) according to a simple embodiment of the invention as described above. Thus in fig. 4 the bit error rate (BER) is depicted as a function of  $E_b/N_0$ , with comparative plots showing the AWGN for a prior art system (old aw gn) and the AWGN for a system according to a simple embodiment of the invention (new aw gn) and comparative plots showing the Rayleigh Fading for a prior art system (old rayleigh) and the Rayleigh Fading for a system according to a simple embodiment of the invention (new rayleigh).

Obviously the performance of other embodiments than described above and the performance of more sophisticated embodiments according to the invention may be significantly better than depicted in fig. 4.

APC is a new technique that integrates antenna polarization and modulation into a new form of codulation. It has potential application to a wide range of modulation techniques employed in wireless and mobile communication systems. The performance benefit is the result of increasing the effective distance between symbols in signal space (i.e., coded or otherwise).

APC can be implemented using existing technology, as well as, integrated into new designs. The example presented above is focused on the application of APC to systems where minimal changes are required in order to integrate antenna polarization with the basedband subsystem (i.e., modulation and coding). Although, in this case, the MSB determines the antenna/polarization, other implementations of

APC are possible and may be advantageous dependent on the system design constraints and complexity.

5 The achievable performance gain is increased further given polarization switching based on other than the MSB, for example, the least significant bit (LSB). This is because the error performance is dominated by the contribution of the nearest neighbors in signal space (least distant). As can be seen from figure 3, the nearest neighbors are separated by the LSB. As such, the potential benefits of APC are more pronounced, i.e. than depicted in fig. 4. The tradeoff is dependent on implementation  
10 complexity and polarization switching speed.

The concept of APC may be combined with multiple input multiple output antennas (MIMO) into space-time codulation technique integrating modulation, coding, antennas and polarization. In the case of the 8-PSK example, 1 channel bit would be  
15 transmitted from each of 3 transmit antennas, each employing a different polarization. However, polarization reuse may be possible and advantageous in some cases e.g. when combined in the context of a MIMO system operating in a multipath fading channel, where spatial separation of signals is possible.

20 Additionally, APC is complimentary to polarization division multiple access (PDMA), i.e. a multiplexing technique using wave polarization (as described in international patent application No. PCT/DK01/00050 ("System for communication" by Prasad, Jyoti et al)) and may be employed together with PDMA.

25 The invention has been explained in the above with reference to general and specific embodiments. However, it will be understood that the invention may be modified in a number of ways, which will be obvious to a person skilled in the art, and that these are included in the scope of the invention defined by the claims.

30 For example other polarizations than right hand and left hand polarization may be employed in connection with the invention, e.g. left and right slant polarization, left and right circular polarization, vertical and horizontal polarization etc. Further, more



than two different polarizations may be utilized as already explained, e.g. three, four etc.

5 As already mentioned, other forms of modulation that the examples mentioned above may be employed in connection with the invention which will be obvious to a person skilled in the art.

10 Further, the antenna polarization may be provided using two or more antennas with different polarizations pr unit, one antenna facilitating multiple polarizations may be provided pr. unit and of course a combination of these two solutions may be provided as well.

**Patent Claims**

1. Method of transmitting digital data signals whereby a modulation of the digital data signals is performed and whereby a coding by means of antenna polarization of the digital data signals is involved.
2. Method according to claim 1, characterized in that said coding involves a switching of antenna polarization between two different polarization values.
3. Method according to claim 1 or 2, characterized in that a switching of antenna polarization between at least three different polarization values are performed.
4. Method according to one or more of claims 1 - 3, characterized in that said modulation is of the M-nary Phase Shift Keying (MPSK)-type, in particular of the M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type.
5. Method according to one or more of claims 1 - 4, characterized in that said switching of antenna polarization is determined by means of at least one bit of a digital package, e.g. a byte or a symbol, which bit may be coded or may be left unencoded by the modulation performed.
6. Method according to one or more of claims 1 - 5, characterized in that said switching of antenna polarization is determined by means of a most significant bit MSB, which may be coded or may be left unencoded by the modulation performed.
7. Method according to one or more of claims 1 - 5, characterized in that said switching of antenna polarization is determined by means of a least significant bit LSB, which may be coded or may be left unencoded by the modulation performed.

8. Method of receiving digital data signals transmitted according to a method according to one or more of claims 1 – 7 whereby a decodulation of the received digital data is performed involving a decoding of the antenna polarization coding and  
5 a demodulation in accordance with the modulation involved.

9. System for transmission of digital data signals comprising means for facilitating a modulation of the digital data signals to be transmitted and means for facilitating a switching of antenna polarization between at least two different polarizations.

10

10. System according to claim 9, characterized in that said system comprises means for receiving transmitted signals, said means for receiving transmitted signals comprising means for performing a decodulation of said signals involving means for performing a decoding in dependence on antenna polarization of  
15 the received digital data and means for performing a demodulation in accordance with the modulation involved.

11. System according to claim 9 or 10, characterized in that said means for performing a modulation and/or said means for performing a demodulation are  
20 operating according to a M-nary Phase Shift Keying (MPSK)-modulation type, in particular to a M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type.

12. System according to one or more of claims 9 - 11, characterized in  
25 that said means for transmitting signals and/or said means for receiving transmitted signals comprise a number of antennas (19, 20) preferably corresponding to the number of polarizations utilized.

13. System according to one or more of claims 9 - 11, characterized in  
30 that said means for transmitting signals and/or said means for receiving transmitted signals comprise an antenna facilitating transmission and/or reception of signals

involving multiple polarizations, preferably corresponding to the number of polarizations utilized.

14. Transmitter for transmission of digital data signals comprising means for  
5 facilitating a modulation of the digital data signals to be transmitted and means for facilitating a switching of antenna polarization between at least two different polarizations.

15. Transmitter according to claim 14, c h a r a c t e r i z e d i n that said means  
10 for performing a modulation are operating according to a M-nary Phase Shift Keying (MPSK)-modulation type, in particular to a M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type.

16. Transmitter according to claim 14 or 15, c h a r a c t e r i z e d i n that said  
15 switching of antenna polarization is determined by means of at least one bit of a digital package, e.g. a byte or a symbol, which bit may be coded or may be left unencoded by the modulation performed and which serves as or establishes a control input for a switching device (18).

20 17. Transmitter according to claim 14, 15 or 16, c h a r a c t e r i z e d i n that said switching of antenna polarization is determined by means of a most significant bit MSB, which may be coded or may be left unencoded by the modulation performed and which serves as or establishes a control input for a switching device (18).

25 18. Transmitter according to claim 14, 15 or 16, c h a r a c t e r i z e d i n that said switching of antenna polarization is determined by means of a least significant bit LSB, which may be coded or may be left unencoded by the modulation performed and which serves as or establishes a control input for a switching device (18).

30

19. Transmitter according to one or more of claims 14 - 18, characterized in that it comprises a number of antennas (19, 20) preferably corresponding to the number of polarizations utilized.
- 5 20. Transmitter according to one or more of claims 14 - 18, characterized in that it comprises an antenna facilitating transmission of signals involving multiple polarizations, preferably corresponding to the number of polarizations utilized.
- 10 21. Receiver for receiving transmitted signals comprising means for performing a decodulation of said signals involving means for performing a decoding in dependence on antenna polarization of the received digital data and means for performing a demodulation in accordance with the modulation involved.
- 15 22. Receiver according to claim 21, characterized in that said means for performing a demodulation are operating according to a M-nary Phase Shift Keying (MPSK)-modulation type, in particular to a M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type.
- 20 23. Receiver according to claim 21 or 22, characterized in that said means for receiving transmitted signals comprise a number of antennas corresponding to the number of polarizations utilized.
24. Receiver according to claim 21 or 22, characterized in that said  
25 means for receiving transmitted signals comprise an antenna facilitating reception of signals involving multiple polarizations, preferably corresponding to the number of polarizations utilized.
25. Transceiver for transmitting and receiving digital data signals comprising means  
30 for facilitating a modulation of the digital data signals to be transmitted, means for facilitating a switching of antenna polarization between at least two different polarizations, means for receiving transmitted signals, said means for receiving

transmitted signals comprising means for performing a decodulation of said signals involving means for performing a decoding in dependence on antenna polarization of the received digital data and means for performing a demodulation in accordance with the modulation involved.

5

26. Transceiver according to claim 25, characterized in that said means for performing a modulation and/or said means for performing a demodulation are operating according to a M-nary Phase Shift Keying (MPSK)-modulation type, in particular to a M-nary Phase Shift Keying (MPSK) Trellis Code Modulation (TCM)-type.

10

27. Transceiver according to claim 25 or 26, characterized in that said means for transmitting signals and/or said means for receiving transmitted signals comprise a number of antennas (19, 20) preferably corresponding to the number of polarizations utilized.

15

28. Transceiver according to claim 25 or 26, characterized in that said means for transmitting signals and/or said means for receiving transmitted signals comprise an antenna facilitating transmission and/or reception of signals involving multiple polarizations, preferably corresponding to the number of polarizations utilized.

20

29. Use of method according to one or more of claims 1 - 8, system according to one or more of claims 9 - 13, transmitter according to one or more of claims 14 - 20, receiver according to one or more of claims 21 - 24 and/or transceiver according to one or more of claims 25 - 28 for wireless communication.

25

30. Use of method according to one or more of claims 1 - 8, system according to one or more of claims 9 - 13, transmitter according to one or more of claims 14 - 20, receiver according to one or more of claims 21 - 24 and/or transceiver according to one or more of claims 25 - 28 for wireless and mobile communication.

30

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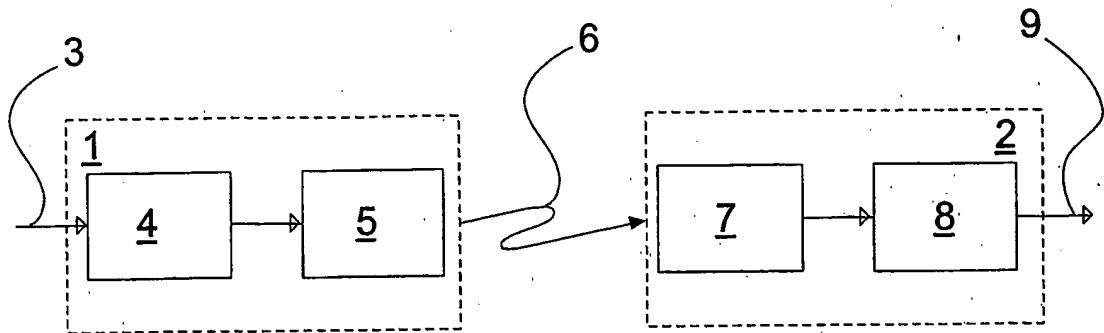


Fig. 1

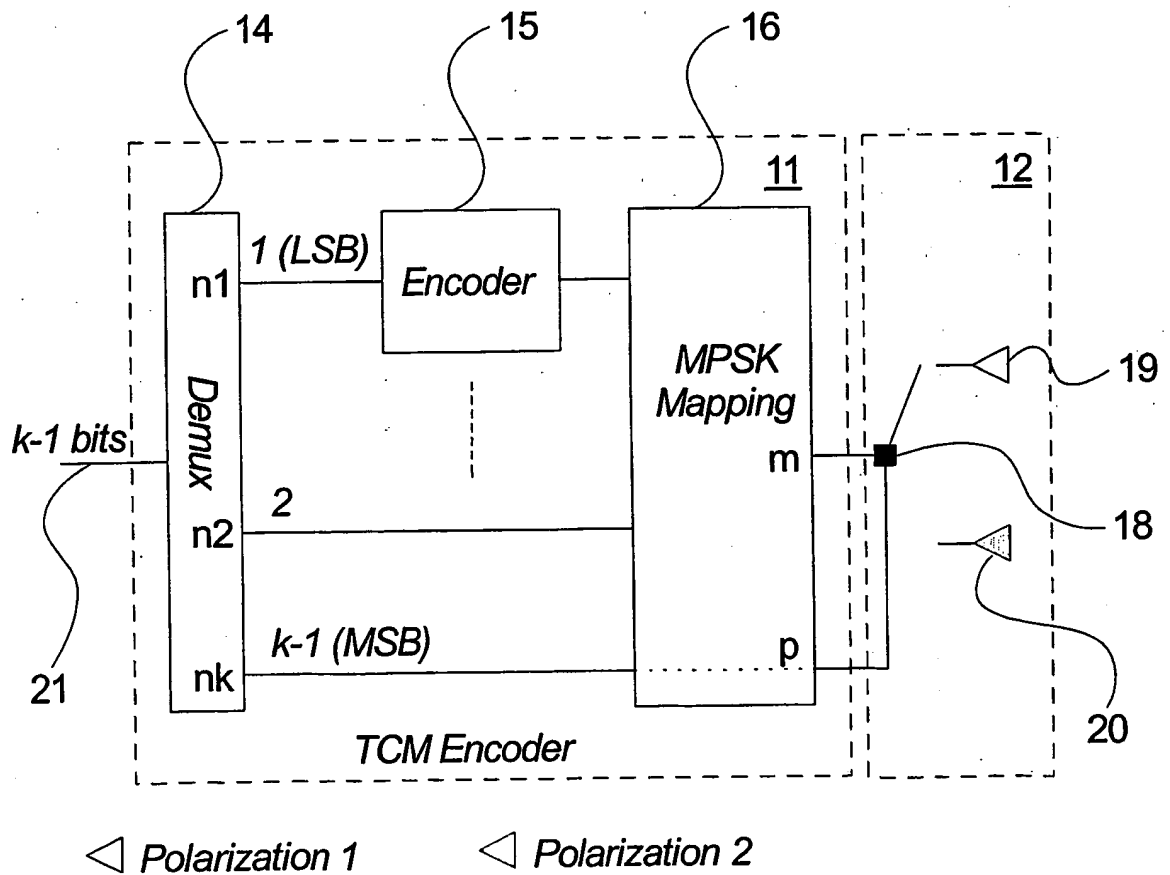


Fig. 2

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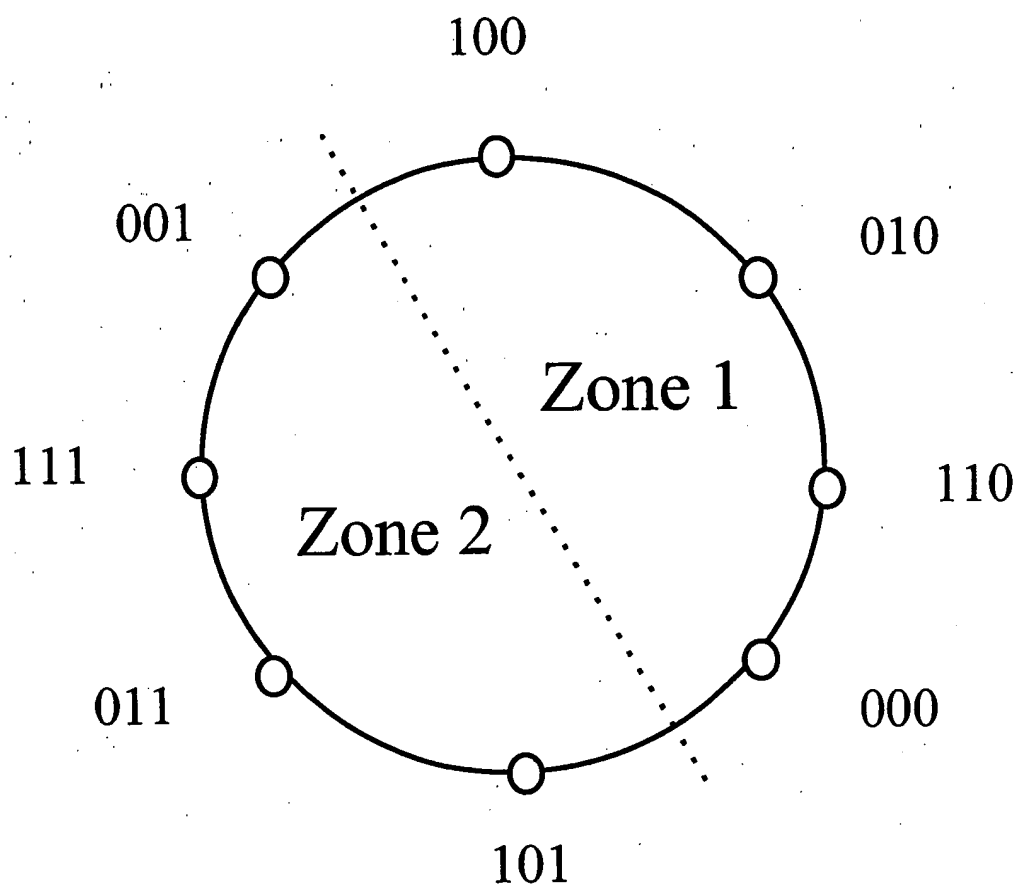


Fig. 3



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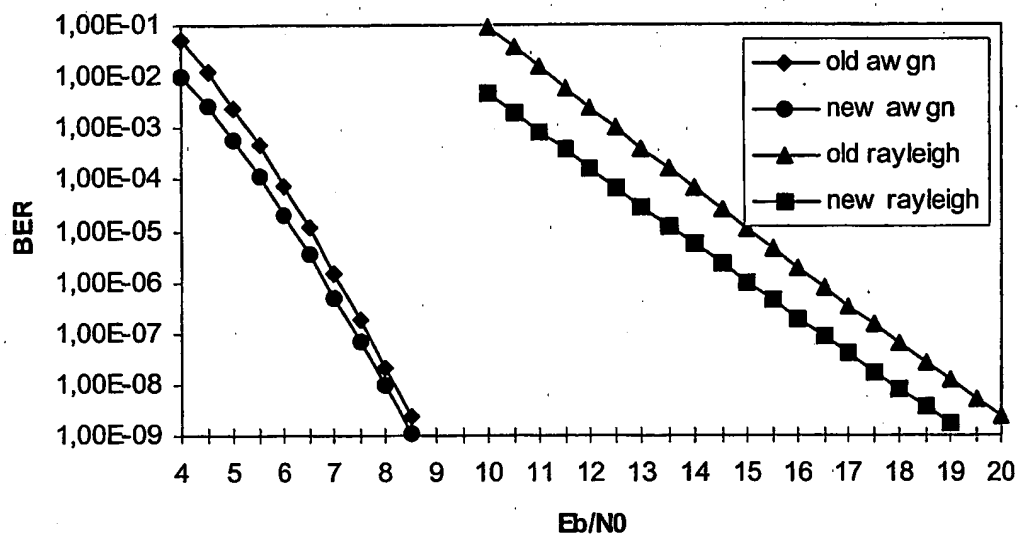


Fig. 4

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/DK 01/00755

## A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H04B 14/00, H04B 7/10, H04B 1/69

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H04B, H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                      | Relevant to claim No.      |
|-----------|---|----------------------------|
| A         | US 5898362 A (IBANEZ-MEIER ET AL), 27 April 1999<br>(27.04.99), column 1 - column 2, abstract<br>--     | 1-30                       |
| X         | US 4521878 A (TOYONAGA), 4 June 1985 (04.06.85),<br>column 1, abstract<br>--                            | 1-3,8,9,14,<br>21,25,29,30 |
| A         | US 6094428 A (BRUCKERT ET AL), 25 July 2000<br>(25.07.00), column 1 - column 2, abstract<br>--<br>----- | 1-30                       |

☐ Further documents are listed in the continuation of Box C.☒ Sec patent family annex.

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"&amp;" document member of the same patent family

Date of the actual completion of the international search

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

10/06/02

International application No.

PCT/DK 01/00755

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s)   | Publication<br>date                                      |
|---|---------------------|--|--|
| US 5898362 A                              | 27/04/99            | FR 2765052 A<br>IT 1299486 B<br>IT RM980347 A<br>WO 9856123 A                    | 24/12/98<br>16/03/00<br>29/11/99<br>10/12/98             |
| US 4521878 A                              | 04/06/85            | DE 3380390 D<br>EP 0085614 A,B<br>JP 58129854 A<br>US 4621512 A<br>JP 59105735 A | 00/00/00<br>10/08/83<br>03/08/83<br>11/11/86<br>19/06/84 |
| US 6094428 A                              | 25/07/00            | BR 9809366 A<br>CN 1254462 T<br>EP 0983645 A<br>JP 2001522561 T<br>WO 9849790 A  | 04/07/00<br>24/05/00<br>08/03/00<br>13/11/01<br>05/11/98 |

Form PCT/ISA/210 (patent family annex) (July 1998)